

**Validation of ADAR System 5500 Digital Imagery
Delivery Task Order #1, Task Request #857 – Brookings, SD**

By

**Lockheed Martin Space Operations – Stennis Programs
John C. Stennis Space Center, MS 39529-6000**

For

**Commercial Remote Sensing Program
National Aeronautics and Space Administration
John C. Stennis Space Center, MS 39529-6000**

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Scope of Work

This work was performed under NASA's Verification and Validation Program as an independent check of data supplied by Positive Systems, Inc. through the Earth Science Enterprise's Scientific Data Purchase (SDP) Program. This document serves as the basis for reporting results associated with validation of multispectral digital imagery according to the specifications of contract NAS 13-98049. The validation was performed under the Positive Systems Imaging System Validation Work Instruction CRSP-WI-28: Spectral registration, spatial resolution, endlaps, sidelaps, and image quality were evaluated. The validation was preceded by Shipment Verification, as described in the Work Instruction CRSP-WI-22: Every image was passed through an automatic ingest verification and thumbnail review process to identify omissions, problems with media integrity, and gross errors in data quality. Validation of metadata files is not within the scope of this report, but it was performed separately.

Data Set

The validation covers the data set provided under Delivery Task Order #1, Task Request #857 – Brookings, SD. This data set consists of 1192 images acquired at four separate sites using the ADAR System 5500 SN11 sensor. Endlaps and sidelaps were first calculated for each site individually and then were averaged for the entire data set. Spectral registration, spatial resolution, and image statistics were calculated for the entire data set at one time.

Conformance Matrix

The following matrix is based on the image product specifications defined in the contract NAS 13-98049, Modification 1. The individual specifications were validated using images acquired either in the laboratory, during a functional flight test, or during a standard flight.

Laboratory characterization

ITEM	SPECIFICATION	Meets Specification
Post-Flight Correction	Correction for lens vignetting effects	YES
	Radiometric adjustment for sensor non-uniformities	YES
	Dark current subtraction (mean value)	YES
Spectral Band Pass	Blue: 450-515 nm Green: 525-605 nm Red: 630-690 nm Near infrared (NIR): 750-860 nm	YES
Spectral Band Pass Accuracy	Band edge points at 50% peak response are within ± 15 nm.	YES
	Slope through the 50% point is at least 15% per 20 nm.	YES
	Out-of-band filter response is less than 5% of the total integrated transmittance within 5% transmission points of that band.	YES
Radiometric Quantization	8 bits per spectral channel	YES
Radiometric Accuracy and Stability	Relative radiometric accuracy to within $\pm 5\%$	YES
	Linearity to within $\pm 5\%$ over the entire imaging exposure dynamic range	YES

ITEM	SPECIFICATION	Meets Specification
	Requirements on banding, streaking, failed, and non-calibrated detectors: 99.5% of all the detectors are within $\pm 5\%$ or ± 1 DN of the mean dark counts of the entire focal plane array.	YES
Spatial Resolution and Image Quality (at all field angles)	Ratio of full width at half maximum (FWHM) of line spread function (derived from an edge target response) to ground sample distance (GSD) is less than two.	YES
	At zero spatial frequency, for all spectral bands, the signal-to-noise ratio (SNR) is greater than 70 for a Lambertian surface with 20% reflectance, illuminated at solar zenith angle of 30 degrees.	YES

Functional flight test

ITEM	SPECIFICATION					Meets Specification
Post-Flight Correction	Dark current subtraction (mean value)					YES
	Spectral co-registration to within 1 pixel at 90% of the project area					YES
Radiometric Accuracy Stability	Linearity to within $\pm 5\%$ over the entire imaging exposure dynamic range					YES
Spatial Resolution and Image Quality (at all field angles)	Terrain	<i>Benign</i>	<i>Rugged</i>	<i>Extreme</i>	<i>Severe</i>	
	Elevation change	less than 200 m	201 m to 750 m	751 m to 1500 m	more than 1501 m	
	GSD in meters	0.7 ± 0.1	0.8 ± 0.2	1.0 ± 0.4	N/A	YES
	FWHM of line spread function (derived from an edge response)	less than 1.5 m	less than 2.0 m	less than 2.8 m	N/A	YES
	90% of endlaps and sidelaps	not smaller than 35%	in the range of 5% to 55%	in the range of 1% to 61%	N/A	YES
	The remaining 10% of endlaps and sidelaps	not smaller than 15%	not smaller than 1%	no gaps	N/A	YES
	At zero spatial frequency, for all spectral bands, the signal-to-noise ratio (SNR) is greater than 70 for a Lambertian surface with 20% reflectance, illuminated at solar zenith angle of 30 degrees.					YES
Absolute Geolocation Accuracy	Frame center point coordinate referenced to ± 100 m in metadata listing					YES

The following images were found to have less than 90% of the samples registered to within one pixel:

c190a_dark_450.lan : 52.1%	c190a_02_082r.lan : 89.7%	c190a_18_181r.lan : 82.1%
c190a_dark_451.lan : 55.2%	c190a_02_093r.lan : 90.0%	c190a_18_182r.lan : 87.5%
c190a_dark_452.lan : 54.0%	c190a_02_103r.lan : 89.6%	c190a_18_186r.lan : 85.0%
c190a_dark_453.lan : 55.0%	c190a_03_179r.lan : 87.8%	c190a_18_187r.lan : 89.8%
c190a_dark_454.lan : 50.9%	c190a_03_180r.lan : 83.3%	c190a_18_204r.lan : 86.5%
c190a_dark_455.lan : 50.0%	c190a_04_237r.lan : 89.5%	c190a_19_249r.lan : 89.3%
c190a_dark_456.lan : 51.4%	c190a_04_244r.lan : 89.3%	c190a_19_254r.lan : 82.4%
c190a_dark_457.lan : 50.8%	c190a_04_248r.lan : 81.9%	c190a_19_260r.lan : 85.4%
c190a_dark_458.lan : 53.0%	c190a_04_249r.lan : 88.9%	c190a_20_313r.lan : 74.8%
c190a_dark_459.lan : 50.9%	c190a_05_306r.lan : 89.1%	c190a_20_315r.lan : 85.5%
c190a_dark_460.lan : 55.9%	c190a_05_317r.lan : 89.7%	c190a_20_316r.lan : 88.7%
c190a_dark_461.lan : 52.0%	c190a_06_064r.lan : 89.6%	c190a_20_322r.lan : 88.7%
c190a_dark_462.lan : 50.7%	c190a_06_065r.lan : 87.2%	c190a_20_323r.lan : 85.3%
c190a_dark_463.lan : 51.3%	c190a_07_117r.lan : 89.0%	c190a_20_325r.lan : 83.1%
c190a_dark_464.lan : 48.6%	c190a_07_120r.lan : 89.4%	c190b_01_010r.lan : 89.9%
c190a_dark_465.lan : 55.3%	c190a_07_131r.lan : 89.7%	c190b_01_011r.lan : 88.8%
c190a_dark_466.lan : 51.3%	c190a_07_135r.lan : 89.4%	c190b_01_013r.lan : 88.8%
c190a_dark_467.lan : 46.0%	c190a_08_187r.lan : 86.4%	c190b_01_018r.lan : 79.5%
c190a_dark_468.lan : 51.6%	c190a_08_189r.lan : 88.3%	c190b_01_019r.lan : 79.5%
c190a_dark_469.lan : 52.6%	c190a_08_192r.lan : 82.3%	c190b_01_020r.lan : 78.3%
c190a_dark_470.lan : 53.6%	c190a_08_193r.lan : 70.6%	c190b_01_021r.lan : 82.1%
c190a_dark_471.lan : 49.8%	c190a_08_195r.lan : 83.5%	c190b_01_022r.lan : 82.7%
c190a_dark_472.lan : 53.8%	c190a_08_196r.lan : 89.3%	c190b_01_023r.lan : 80.6%
c190a_dark_473.lan : 53.3%	c190a_08_200r.lan : 89.7%	c190b_01_024r.lan : 84.3%
c190a_dark_474.lan : 57.0%	c190a_08_206r.lan : 89.4%	c190b_01_025r.lan : 83.0%
c190a_dark_475.lan : 54.1%	c190a_09_261r.lan : 88.7%	c190b_01_026r.lan : 83.6%
c190a_dark_476.lan : 53.1%	c190a_09_262r.lan : 83.6%	c190b_02_071r.lan : 86.5%
c190a_dark_477.lan : 57.2%	c190a_09_265r.lan : 89.6%	c190b_02_072r.lan : 81.8%
c190a_dark_478.lan : 51.7%	c190a_10_323r.lan : 89.2%	c190b_02_073r.lan : 79.5%
c190a_dark_479.lan : 55.9%	c190a_11_033r.lan : 88.3%	c190b_02_074r.lan : 82.8%
c190a_dark_480.lan : 56.8%	c190a_12_103r.lan : 85.6%	c190b_02_076r.lan : 88.4%
c190a_dark_481.lan : 57.4%	c190a_13a_385r.lan : 86.3%	c190b_02_081r.lan : 88.3%
c190a_dark_482.lan : 50.5%	c190a_13a_386r.lan : 80.3%	c190b_02_082r.lan : 83.3%
c190a_dark_483.lan : 54.9%	c190a_13a_388r.lan : 88.9%	c190b_03_135r.lan : 86.2%
c190a_dark_484.lan : 56.8%	c190a_13a_410r.lan : 87.9%	c190b_04_170r.lan : 89.8%
c190a_dark_485.lan : 57.7%	c190a_14_234r.lan : 78.2%	c190b_04_171r.lan : 89.6%
c190a_dark_486.lan : 53.4%	c190a_14_236r.lan : 80.3%	c190b_04_180r.lan : 88.7%
c190a_dark_487.lan : 51.1%	c190a_14_237r.lan : 81.7%	c190b_04_183r.lan : 88.3%
c190a_dark_488.lan : 57.5%	c190a_14_238r.lan : 89.9%	c190b_04_187r.lan : 85.8%
c190a_dark_489.lan : 58.1%	c190a_15_278r.lan : 87.5%	c190b_05_228r.lan : 89.6%
c190a_dark_490.lan : 53.8%	c190a_15_300r.lan : 89.4%	c190b_06_274r.lan : 89.2%
c190a_dark_491.lan : 56.4%	c190a_15_303r.lan : 86.8%	c190b_06_275r.lan : 89.9%
c190a_dark_492.lan : 60.3%	c190a_15_304r.lan : 86.8%	c190b_06_281r.lan : 90.0%
c190a_dark_493.lan : 56.3%	c190a_15_305r.lan : 82.7%	c190b_06_284r.lan : 88.1%
c190a_dark_494.lan : 54.7%	c190a_15_306r.lan : 82.1%	c190b_06_287r.lan : 88.0%
c190a_dark_495.lan : 54.9%	c190a_15_307r.lan : 82.1%	c190b_06_288r.lan : 87.0%
c190a_dark_496.lan : 62.4%	c190a_15_308r.lan : 87.0%	c190b_07_335r.lan : 88.1%
c190a_dark_497.lan : 59.6%	c190a_16_042r.lan : 88.7%	c190b_07_341r.lan : 82.5%
c190a_dark_498.lan : 53.4%	c190a_16_047r.lan : 87.3%	c190b_08_036r.lan : 88.9%
c190a_dark_499.lan : 58.2%	c190a_16_059r.lan : 88.2%	c190b_08_038r.lan : 85.3%
c190a_dark_500.lan : 57.4%	c190a_17b_416r.lan : 86.0%	c190b_08_039r.lan : 89.5%
c190a_dark_501.lan : 55.9%	c190a_17b_417r.lan : 85.9%	c190b_08_050r.lan : 80.6%
c190a_01b_375r.lan : 83.2%	c190a_17b_425r.lan : 88.8%	c190b_08_052r.lan : 84.7%
c190a_01b_378r.lan : 88.9%	c190a_17b_428r.lan : 89.6%	c190b_08_053r.lan : 88.1%
c190a_01b_381r.lan : 88.0%	c190a_17b_436r.lan : 89.9%	c190b_08_054r.lan : 88.8%
c190a_01b_382r.lan : 89.6%	c190a_17b_437r.lan : 88.2%	c190b_09_087r.lan : 88.7%
c190a_01b_383r.lan : 88.7%	c190a_18_174r.lan : 89.0%	c190b_09_088r.lan : 84.3%

c190b_09_089r.lan : 81.8%	c190b_14_369r.lan : 86.9%	c190c_15_438r.lan : 81.7%
c190b_09_093r.lan : 82.3%	c190b_14_371r.lan : 86.7%	c190c_15_440r.lan : 81.9%
c190b_09_094r.lan : 89.2%	c190b_15_377r.lan : 88.7%	c190c_15_441r.lan : 90.0%
c190b_09_098r.lan : 88.4%	c190b_15_378r.lan : 77.8%	c190c_15_442r.lan : 82.6%
c190b_09_106r.lan : 87.6%	c190b_15_379r.lan : 83.5%	c190c_16_525r.lan : 81.3%
c190b_09_107r.lan : 87.7%	c190b_15_380r.lan : 89.4%	c190c_16_526r.lan : 83.7%
c190b_09_108r.lan : 89.9%	c190b_15_381r.lan : 78.3%	c190c_16_527r.lan : 85.3%
c190b_09_109r.lan : 88.3%	c190b_15_391r.lan : 83.7%	c190c_16_529r.lan : 86.5%
c190b_09_110r.lan : 86.3%	c190b_15_392r.lan : 86.8%	c190c_16_532r.lan : 89.4%
c190b_10_139r.lan : 89.5%	c190b_15_393r.lan : 87.0%	c190c_16_533r.lan : 82.6%
c190b_10_140r.lan : 87.3%	c190b_15_394r.lan : 83.4%	c190c_16_534r.lan : 88.2%
c190b_10_141r.lan : 82.3%	c190b_15_395r.lan : 88.0%	c190c_16_537r.lan : 89.9%
c190b_10_142r.lan : 81.0%	c190b_15_396r.lan : 82.1%	c190c_16_546r.lan : 88.8%
c190b_10_144r.lan : 85.6%	c190b_15_399r.lan : 89.0%	c190c_16_554r.lan : 89.9%
c190b_11_195r.lan : 88.9%	c190c_14_491r.lan : 89.9%	c190c_16_555r.lan : 89.4%
c190b_12_250r.lan : 88.3%	c190c_14_492r.lan : 89.5%	c190c_17_447r.lan : 78.8%
c190b_12_251r.lan : 85.8%	c190c_14_493r.lan : 84.4%	c190c_17_448r.lan : 83.3%
c190b_12_252r.lan : 84.4%	c190c_14_499r.lan : 88.6%	c190c_17_455r.lan : 87.2%
c190b_12_264r.lan : 88.6%	c190c_14_515r.lan : 80.3%	c190c_17_456r.lan : 88.4%
c190b_12_266r.lan : 89.8%	c190c_14_516r.lan : 83.6%	c190c_17_457r.lan : 84.7%
c190b_13_298r.lan : 87.8%	c190c_14_517r.lan : 89.5%	c190c_17_468r.lan : 88.2%
c190b_13_299r.lan : 83.9%	c190c_14_518r.lan : 88.6%	c190c_17_469r.lan : 87.9%
c190b_14_349r.lan : 88.9%	c190c_14_519r.lan : 87.5%	c190c_17_471r.lan : 84.9%
c190b_14_350r.lan : 89.6%	c190c_14_520r.lan : 89.7%	c190c_17_477r.lan : 88.6%
c190b_14_353r.lan : 87.9%	c190c_15_412r.lan : 88.9%	c190c_17_479r.lan : 89.3%
c190b_14_354r.lan : 89.4%	c190c_15_413r.lan : 86.2%	
c190b_14_355r.lan : 86.3%	c190c_15_434r.lan : 85.9%	
c190b_14_358r.lan : 88.7%	c190c_15_435r.lan : 85.0%	
c190b_14_367r.lan : 89.9%	c190c_15_437r.lan : 85.2%	

Spatial resolution, endlaps, and sidelaps

These calculations are based on geographic coordinates of image centers as well as aircraft altitudes and headings provided in the Global Positioning System (GPS) file. Image sizes used in the calculations were obtained from the actual image files. Ground elevation data were acquired automatically from the U.S. Geological Survey's Digital Elevation Maps (DEM) in the 1:250,000 scale with horizontal resolution of 100 m. The specified absolute horizontal accuracy of the DEM is 130 m, while the specified absolute vertical accuracy is ± 30 m. Detector pitch and effective focal length provided in laboratory calibration reports were utilized in calculations of the ground sample distance.

This data set was acquired over a benign terrain: the maximum elevation change at any site is 33 meters. Figure 3 shows estimated terrain elevation at center point of every image.

Ground sample distance estimated for a center point of every image is shown in Figure 4. For all the images in this data set, GSD is within a range from 0.72 m to 0.77 m, which is enclosed in the range specified in the contract for the benign terrain. Therefore, values of GSD do meet contract specifications.

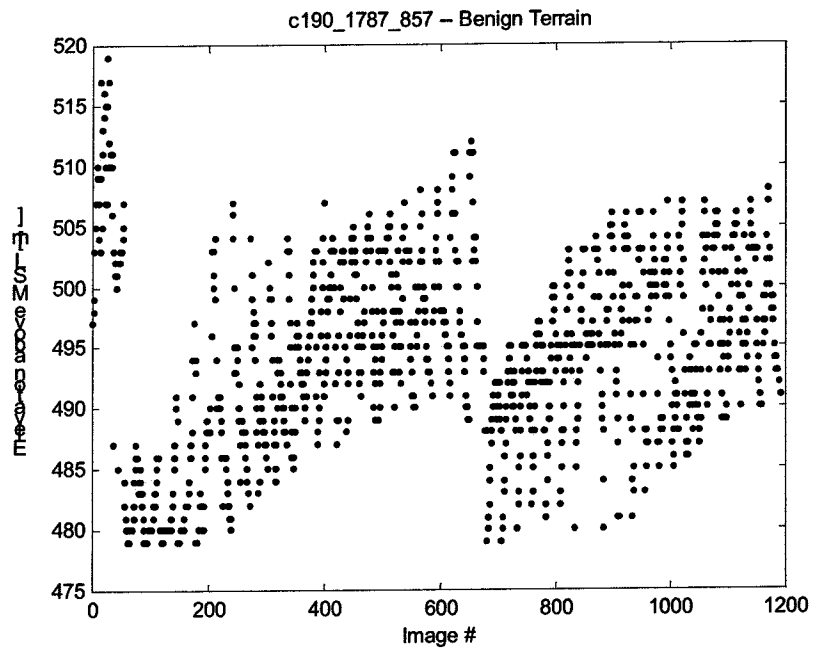


Figure 3. Terrain elevation above mean sea level (MSL) at center point of each image.

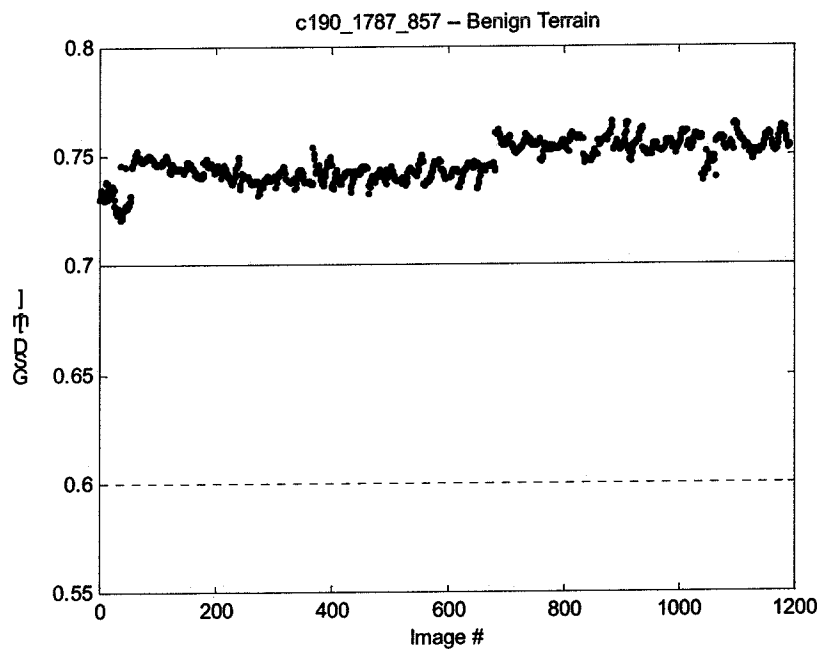


Figure 4. Estimated ground sample distance (GSD) at center point of each image.

Results of the calculations of endlaps and sidelaps are shown in Table 1 and Table 2, respectively. For the entire data set, 99.6% of endlaps and 98.6% of sidelaps are larger than the required 35%. The smallest endlap is 28%, and the smallest sidelap is 32%. There are no gaps between images. Therefore, both the endlaps and the sidelaps between images do meet contract specifications.

Table 1. Statistics of the calculated endlaps.

<i>Site ID</i>	<i>Mean</i>	<i>Std. Dev.</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Not Smaller than 35%</i>
c190a	48%	5.0%	37%	56%	100.0%
c190a dark	49%	7.9%	35%	62%	94.1%
c190b	48%	5.0%	28%	65%	99.5%
c190c	48%	4.9%	41%	56%	100.0%
ENTIRE DATA SET			28%		99.6%

Table 2. Statistics of the calculated sidelaps.

<i>Site ID</i>	<i>Mean</i>	<i>Std. Dev.</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Not Smaller than 35%</i>
c190a	47%	5.4%	33%	62%	98.2%
c190a dark	N/A	N/A	N/A	N/A	N/A
c190b	48%	5.1%	32%	68%	98.9%
c190c	48%	3.7%	41%	56%	100.0%
ENTIRE DATA SET			32%		98.6%

Image quality

Evaluation of image quality is based on various types of statistics, which are used to characterize distribution of DN's in an image. The following statistics are calculated for each band of every image: mean digital number (DN), minimum DN, maximum DN, and pixel saturation. Saturation is measured as the percentage of pixels in an image that have DN equal to the maximum DN possible at a given quantization (for example, the maximum DN equals 255 for the 8-bit quantization). The statistics are used to detect anomalies in the image quality: Images with atypical statistics are examined interactively using remote-sensing image processing software such as *ERDAS IMAGINE* or *ENVI*.

Mean DN's that are shown in Figure 5 do not indicate any anomalies (such as shutter failure) in image quality. Values of minimum DN show that in many images some pixels have DN of zero. Visual inspection of the images reveals that such pixels occur on the image edges in the corner regions. These pixels are artifacts that originate from the band-to-band registration process. As shown in Figure 6, some images also have saturated pixels (DN of 255).

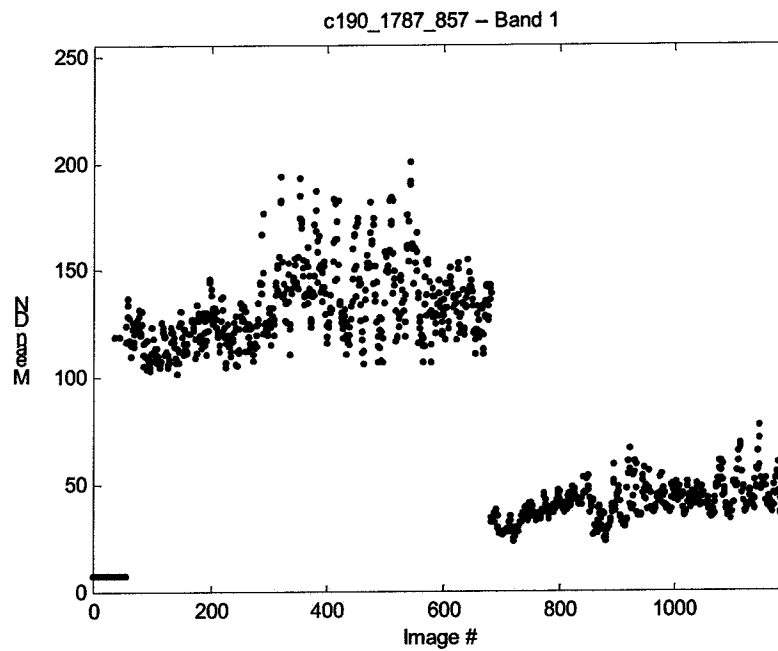


Figure 5a. Mean DN's for Band 1 (Blue) of each image.

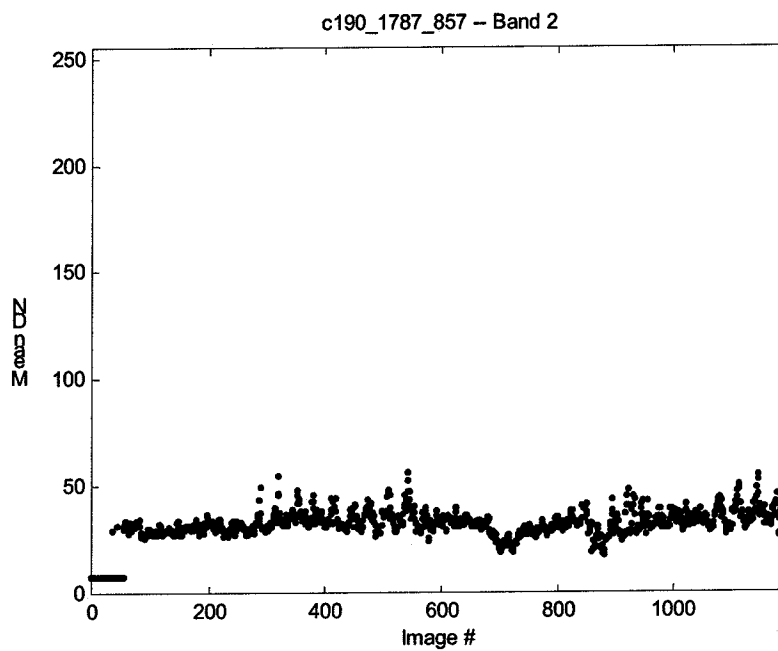


Figure 5b. Mean DN's for Band 2 (Green) of each image.

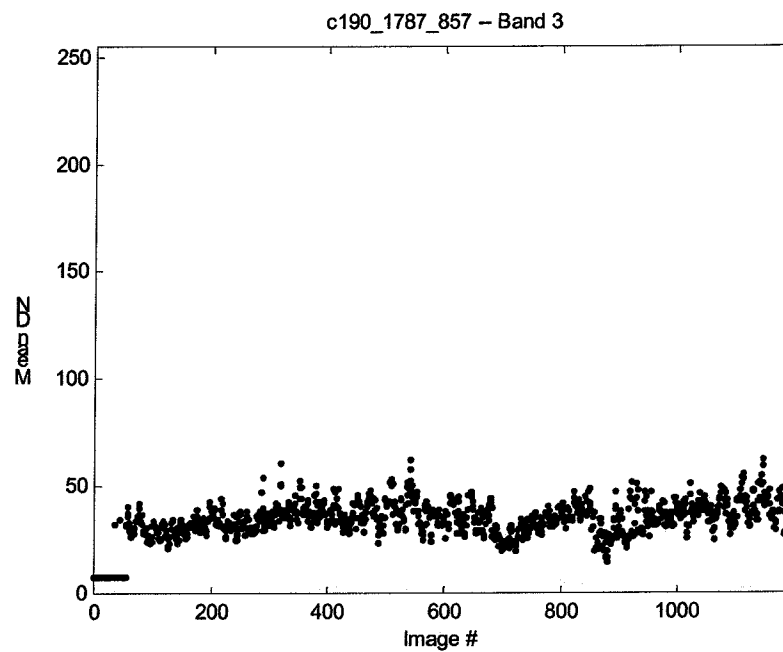


Figure 5c. Mean DN's for Band 3 (Red) of each image.

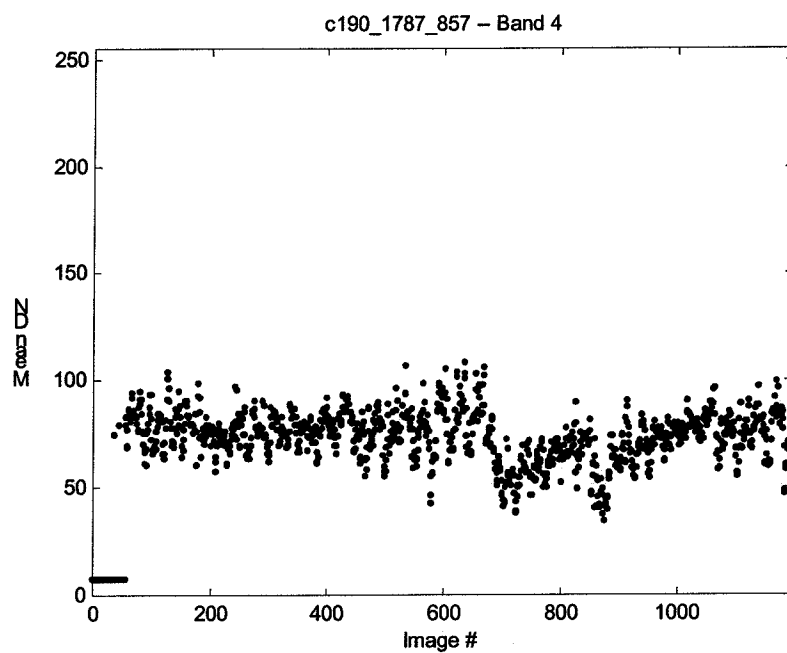


Figure 5d. Mean DN's for Band 4 (NIR) of each image.

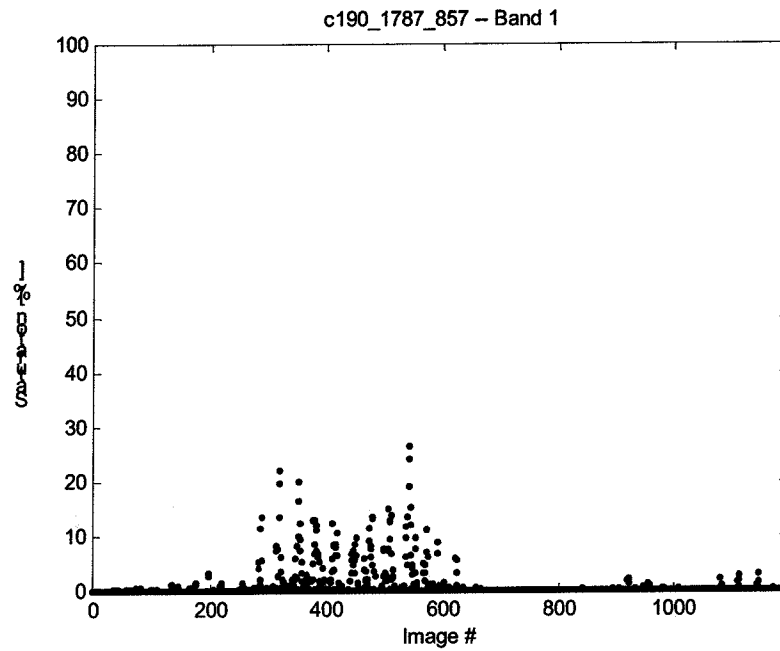


Figure 6a. Fraction of saturated pixels for Band 1 (Blue) of each image.

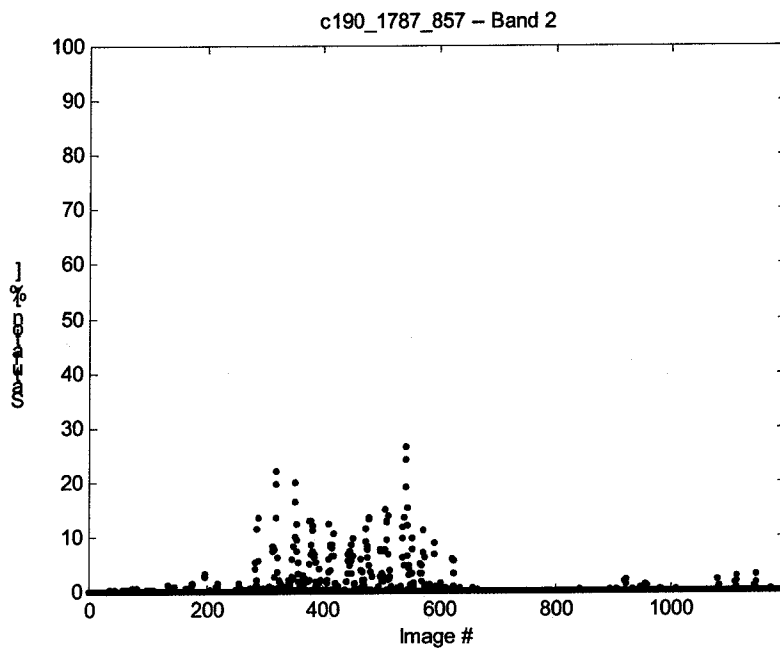


Figure 6b. Fraction of saturated pixels for Band 2 (Green) of each image.

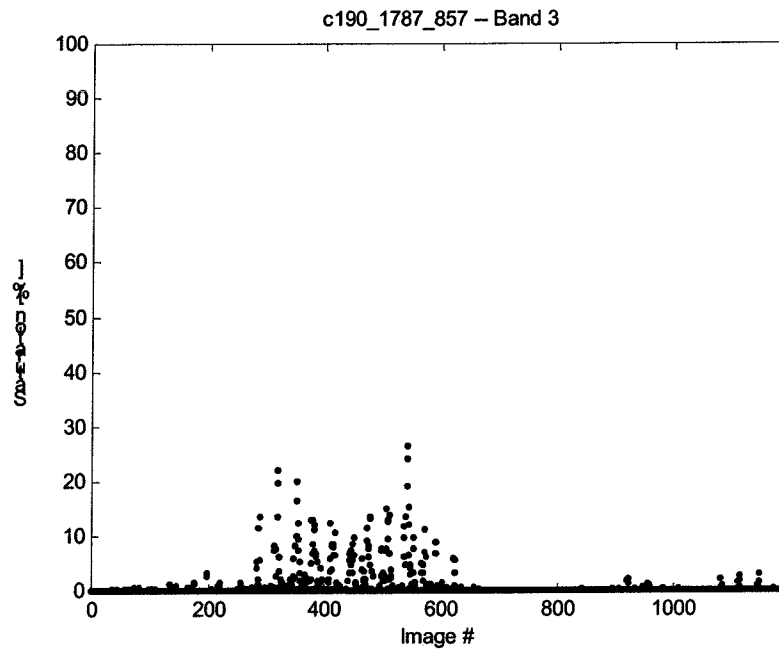


Figure 6c. Fraction of saturated pixels for Band 3 (Red) of each image.

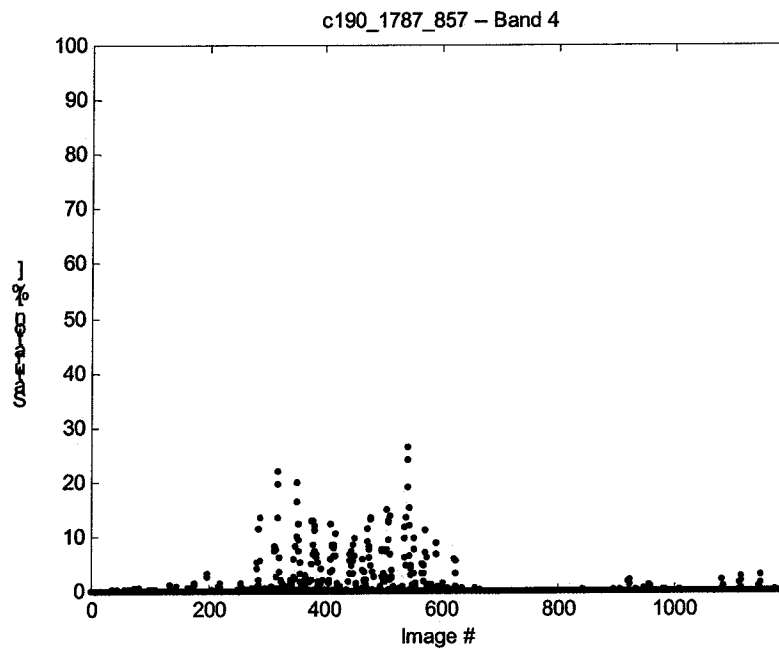


Figure 6d. Fraction of saturated pixels for Band 4 (NIR) of each image.

Appendix A: List of the Evaluated Images (Image Index)

1 : c190a_dark_450.lan	60 : c190a_01b_365r.lan	119 : c190a_03_154r.lan
2 : c190a_dark_451.lan	61 : c190a_01b_366r.lan	120 : c190a_03_155r.lan
3 : c190a_dark_452.lan	62 : c190a_01b_367r.lan	121 : c190a_03_156r.lan
4 : c190a_dark_453.lan	63 : c190a_01b_368r.lan	122 : c190a_03_157r.lan
5 : c190a_dark_454.lan	64 : c190a_01b_369r.lan	123 : c190a_03_158r.lan
6 : c190a_dark_455.lan	65 : c190a_01b_370r.lan	124 : c190a_03_159r.lan
7 : c190a_dark_456.lan	66 : c190a_01b_371r.lan	125 : c190a_03_160r.lan
8 : c190a_dark_457.lan	67 : c190a_01b_372r.lan	126 : c190a_03_161r.lan
9 : c190a_dark_458.lan	68 : c190a_01b_373r.lan	127 : c190a_03_162r.lan
10 : c190a_dark_459.lan	69 : c190a_01b_374r.lan	128 : c190a_03_163r.lan
11 : c190a_dark_460.lan	70 : c190a_01b_375r.lan	129 : c190a_03_164r.lan
12 : c190a_dark_461.lan	71 : c190a_01b_376r.lan	130 : c190a_03_165r.lan
13 : c190a_dark_462.lan	72 : c190a_01b_377r.lan	131 : c190a_03_166r.lan
14 : c190a_dark_463.lan	73 : c190a_01b_378r.lan	132 : c190a_03_167r.lan
15 : c190a_dark_464.lan	74 : c190a_01b_379r.lan	133 : c190a_03_168r.lan
16 : c190a_dark_465.lan	75 : c190a_01b_380r.lan	134 : c190a_03_169r.lan
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26 : c190a_dark_475.lan	85 : c190a_02_082r.lan	144 : c190a_03_179r.lan
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